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A REVIEW ON STRESS BLOCK PARAMETERS OF HIGH PERFORMANCE CONCRETE

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ABSTRACT

High-performance concrete (HPC) is widely used in large scale concrete constructions that require high strength, high flow ability and high durability. Various studies were performed on high performance concrete with respect to workability, strength and durability. High-performance concrete exceeds the properties and constructability of normal concrete. But the design parameters adopted as per IS: 456 is based on the stress block parameters of conventional concrete and this leads to a conservative design. The present study focuses on reviewing the stress block parameters of high performance concrete so that it can be used in design of structural elements using high performance concrete.

KEYWORDS: Compressive Strength, High Performance Concrete, Modulus of Elasticity, Stress Block Parameters, Stress-Strain Curve

INTRODUCTION

Concrete is the most widely used construction material in India with annual consumption exceeding 100 million cubic meters. Conventional Ordinary Portland Cement Concrete which was designed on the basis of compressive strength does not meet many functional requirements as it was found deficit in aggressive environments, time of construction, energy absorption capacity, repair and retrofitting jobs etc. So, there was a need to design High Performance Concrete which is far superior to conventional concrete as the ingredients of High Performance Concrete contribute most efficiently to the various properties.

HIGH PERFORMANCE CONCRETE

Definition of the high performance concrete has been changing with time, geographical area and production technology. Concrete which has 80–100MPa compressive strength has been used in reinforced concrete and prestressed concrete structures. High performance concrete about 250MPa compressive strength has been able to produced by using high strength aggregate. High-performance concrete characteristics are developed for particular applications and environments; some of the properties that may be required include high strength, high early strength, high modulus of elasticity, high abrasion resistance, high durability and long life in severe environments, low permeability and diffusion, resistance to chemical attack, high resistance to frost and scaling damage, toughness and impact resistance, volume stability, ease of placement, compaction without segregation, inhibition of bacterial and mold growth.

STRESS-BLOCK PARAMETERS

The design of reinforced concrete members was on the basis of theexisting stress-block parameters, which were

originally formulated by Hognestad [3]. A stress-strain model and a rectangular stress block were proposed by them for use in flexural analysis and design of reinforced concrete sections. Whitney suggested the replacement of actual shape of concrete compressive block by an equivalent rectangle as a means of simplification. For determining flexural capacities, the magnitude k_1, k_3 and position $k_2$of the total compression force need to be known. A lot of investigations were verified to define the stress strain relationship and equivalent stress block parameters in the design of high performance concrete members. Although high performance concrete was commonly used, its properties are not known as much as the properties of ordinary concrete in the design of reinforced concrete sections. High performance concrete was produced using high strength aggregate and cement, water, mineral and chemical admixtures. The decision of using high-performance concrete (HPC) for the design of high-rise structures provides enough benefits that will make it worthwhile to be considered as an economical and attractive option. Once the use of HPC becomes more popular, the importance of research contribution in providing technical knowledge on this new material becomes apparent. The current empirical equations presented in codes, standards, and recommended practices for estimating stress-block parameters are on the basis of tests of concrete with strength of approximately 55MPa. It was not exactly known whether they could be used in the design of structures constructed by using HPC.

LITERATURE REVIEW

Mander et.al (1988) developed a stress-strain model was developed for concrete subjected to uniaxial compressive loading and confined by transverse reinforcement. The concrete section may contain any general type of confining steel: either spiral or circular hoops; or rectangular hoops with or without supplementary cross ties. These cross ties can have either equal or unequal confining stresses along each of the transverse axes. A single equation was used for the stress-strain equation. The model allows for cyclic loading and includes the effect of strain rate. The influence of various types of confinement was taken into account by defining an effective lateral confining stress, which was dependent on the configuration of the transverse and longitudinal reinforcement. An energy balance approach was used to predict the longitudinal compressive strain in the concrete corresponding to first fracture of the transverse reinforcement by equating the strain energy capacity of the transverse reinforcement to the strain energy stored in the concrete as a result of the confinement [1].

VijayaRangan (1998) High-performance high-strength concrete (HPHSC) was defined as concrete that meets special performance and uniformity requirements which cannot always be achieved by using only the conventional materials and normal mixing, placing, and curing practices. The performance requirements may include ease of placement and compaction without segregation, enhanced short term and long-term mechanical properties, high-early-age strength and long life in severe environments. HPHSC is usually proportioned with a low water-to cementitious materials ratio and has a high compressive strength in the range of 50 to 100MPa (7 to 15 ksi). The supplementary cementitious materials may include blast furnace slag, fly ash, or silica fume, which were used either as cement replacement or as additives to the concrete mixture. Considerable information was already available in the literature regarding HPHSC. Several codes have design proposals to include HPHSC. The aim of this paper was to review the existing information and to suggest certain proposals for the design of HPHSC beams, columns, and walls. These proposals cover concrete grades in the range of 20 to 100MPa [2].

Oztekin et.al (2003) Despite so much research on high performance concrete, the properties of this concrete were not known as well as those of ordinary concrete. There have been a lot of equations, rules and suggestions in the codes

which were used in the design of reinforced concrete and prestressed concrete structures. They were obtained from experimental studies made on concrete that have compressive strength of less than about 40MPa. It was not exactly known whether they could be used in the design of structures constructed by using high performance concrete. Therefore in this study, stress-strain and equivalent block parameters were obtained from experimental stress-strain diagrams for calculation of high performance reinforced concrete beams in flexure. The conclusions obtained from this study showed that determined rectangular stress block parameters can be used in the design of high performance reinforced concrete members in flexure. Rectangular stress block parameters used in ordinary concrete members cannot be used safely for high performance concrete members. New stress block parameters have been obtained from the experimental study. Then equivalent rectangular stress block parameters were defined using the modified stress-strain model for high performance concrete. These parameters were in a harmony with values obtained from experimental stress-strain curves. Therefore these parameters were able to use in design of the high performance concrete members [3].

Ozbakkaloglu and Saatcioglu (2004) A rectangular stress block was developed for HSC based on an analytical model for concrete stress-strain relationship and a large volume of column test data. The stress block was verified extensively against column tests conducted under concentric and eccentric loadings. The results indicate good correlations of computed and measured strength values. The proposed stress block resembles that currently used in the ACI 318 Code1 and applies to both HSC and normal strength concrete elements. It incorporates prevalent features of HSC in columns that consist of premature spalling of cover under concentric loading, nearly triangular variation of stress-strain relationship under strain gradient and the brittle nature of failure. The proposed stress block was also shown to produce equally good estimates of column strengths for normal strength concrete [4].

Ali Abdul Hussein Jawad Al-Ghalib (2007) The continuous increase in the concrete strength has called for adapting and amending the rectangular stress block parameter values recommended by provisions. This study reviews several different mathematical stress-strain models, and adopts a numerical technique through which a complete stress-strain curve characteristic for any strength was determined. The study highlights the effect of stress-strain model on equivalent stress block parameters. The paper illustrates the variation of the new parameter values against concrete strength together with those of provisions and of other studies. For the purpose of safe, economic, and vast use; the author suggests two formulas to calculate modified stress block parameters [5].

Mertol et.al (2008) describes fundamental characteristics of the compressive stress distribution in the compression zone of flexural members with concrete compressive strengths up to 18 ksi (124 MPa). The proposed model was based on testing of 21 plain concrete specimens subjected to combined flexure and axial compression up to failure. The main variable considered was the strength of concrete that ranged from 10.4 to 16ksi (71.7 to 110.3MPa). Each specimen was subjected to two independent loads with a specific configuration to induce maximum compressive strain at one face and zero strain at the opposite. The measured stress-strain curves and stress block parameters were compiled with the data found in the literature. The data obtained herein were used to determine the fundamental characteristics of the stress distribution in the compression zone of a flexural member. The test results obtained in this research combined with the available data in the literature were used to develop recommended changes for code provisions. The following conclusions can be drawn with respect to flexural design with HSC up to 18ksi (124MPa). The assumption that plane sections remain plane after deformation was valid. The ultimate concrete compressive strain value of 0.003 for design by the current code provision was acceptable. A Poisson’s ratio of 0.2 as used in the current code provision was also acceptable [6].

Braga et.al (2008) In order to evaluate the capacity of RC members, the main codes allow the use of stress-strain laws that can reproduce closely the real behavior of concrete, as opposed to parabola-rectangular or equivalent rectangular diagrams. Both sectional strength and ductility depend on the law of concrete, therefore they were influenced by the confinement of members, as evidenced in the literature. In this paper a possible design approach is presented, based on classic section analysis methods. The method uses parameters that represent the stress-strain law of confined concrete. The studies carried out show that such parameters can be chosen through simple relationships depending on the strength of non-confined concrete, on the amount and geometry of longitudinal and transverse reinforcement, and on the geometry of the section. At this aim some numerical analyses have been performed using an analytical model of confined concrete, capable of taking into account all the mentioned effects, even in the case of various sources of confinement, when different types of hoops and external elements (FRP wrappings, steel plates, etc.) were used. More in detail, the section interaction diagrams for the different limit states requires the definition of an appropriate upper bound for the strain of concrete. Therefore the study focuses on the possibility of using stress-blocks depending on the maximum stain assumed, or on the level of residual stress accepted in concrete according to a specified limit state. Further studies will extend the parametric analysis in order to obtain design equations to be implemented in codes [7].

Noguchi et.al (2009) Many empirical equations for predicting the modulus of elasticity as a function of compressive strength can be found in the current literature. They were obtained from experiments performed on a restricted number of concrete specimens subjected to uniaxial compression. Thus, the existing equations cannot cover the entire experimental data. This was due to the fact that mechanical properties of concrete were highly dependent on the types and proportions of binders and aggregates. To introduce a new reliable formula, more than 3000 data sets, obtained by many investigators using various materials, have been collected and analyzed statistically. The compressive strengths of the considered concretes range from 40 to 160MPa. As a result, a practical and universal equation, which also takes into consideration the types of coarse aggregates and mineral admixtures, was proposed. To obtain a practical and universal equation for the modulus of elasticity, multiple regression analyses have been conducted by using a large amount of data. As a result, an equation applicable to a wide range of aggregates and admixtures was introduced for different concretes, from normal to high strength. The modulus of elasticity of both normal-strength and high-strength concretes seems to be in direct proportion to the cube root of compressive strength, according to the European Code10-11 rules. Similarly, there was a direct proportionality between elastic modulus of concrete and its unit weight power to 2. Conversely, in the formulas proposed by Japanese13 and American12 Code rules, unit weight appears with an exponent c = 1.5. In addition to compressive strength and unit weight of concrete, the modulus of elasticity needs to be expressed as a function of the lithological type of coarse aggregate and the type and amount of admixtures. For the sake of simplicity, these effects can be considered by means of two correction factors, k_1 and k_2, which were equal to 1 in the case of ordinary mixtures [8].

Peng et.al (2011) The equivalent rectangular concrete stress block was widely adopted in flexural strength design of normal-strength reinforced concrete members. From the past research work reported by other researchers, the equivalent stress block parameters was assumed to be dependent only on concrete strength. Nonetheless, the theoretical flexural strengths predicted by the currently used codes were often significantly lower than the actual strengths. In this study, the authors studied the characteristics of equivalent concrete stress block by investigating other factors than concrete strength only. In total 14 inverted T-shaped specimens in 6 groups were fabricated and tested. Each group had identical cross section properties and contained one concentrically loaded specimen and one/several eccentrically loaded specimen(s). The equivalent concrete stress block parameters of the eccentrically loaded specimen were obtained by adopting the modified

stress-strain curve of its counterpart concentrically loaded specimen using a numerical analysis method. Based on the experimental results, the authors found that the equivalent stress block parameters were dependent on strain gradient besides concrete strength. A new set of equivalent rectangular concrete stress block parameters incorporating strain gradient effects were proposed for design purpose, and their validities were verified by comparing with the measured flexural strengths of beams and columns tested by previous researchers [9].

Karthikand Mander (2011) The proposed analytic stress-strain relation represents well the behavior of both normal strength and high-strength concrete in their unconfined and confined states. The stress-strain model can be conveniently integrated in order to obtain the stress-block parameters. In this study, the stress-block parameters were derived from an analytic stress-strain model that was proposed to be particularly useful for hand analysis checks of various computational moment-curvature solutions. To overcome a shortcoming of existing commonly used stress-strain models that were not easy to integrate, a new stress-strain model was proposed and validated for a wide range of concrete strengths and confining stresses. The efficiency of the equivalent rectangular stress-block parameters was demonstrated for hand calculations in predicting key moment-curvature results for a confined concrete column. Results were compared with those obtained from a computational fiber-element analysis using the proposed stress-strain model and another widely used existing model; good agreement between the two was observed [10].

Khadiranaikar and Awati (2012) Most of the existing codes were using stress-block parameters which were derived for normal strength concrete. Several researchers in the past have reported that use of ACI 318 stress-block parameters results in un-conservative design of reinforced concrete members for high-performance concrete (HPC). Recent revision of Indian Standard Code IS 456 for design of reinforced members does not include the provisions for strength of concrete beyond 55MPa. Present research aims at developing the stress-block parameters for wide range of concrete strength between 40–120MPa. The experimental program includes testing of plain concrete columns, reinforced concrete members such as eccentrically loaded columns, and beams in pure flexure. Moment interaction curves were developed for the column data of the present and previous research. An error analysis was incorporated to prove the consistent conservativeness obtained by the use of the proposed stress-block parameters. This study includes 36 HPC members including 18 of the type tested by Hognestad 14 columns in eccentric compression, and 4 beams. The main variable was the strength of concrete in the range of 40–120 MPa. The obtained data was used to generate the concrete stress distribution factors in the compression zone (stress block parameters). The new model was proposed to evaluate ERSB parameters and they were validated with 105 column test data. The following conclusions were drawn for the design of flexural members with HPC up to 120 MPa. The parameters α and β proposed in this study were 0.85 each for 20 MPa strength of concrete and subsequently, for every 20-MPa increase in strength α was reduced by 0.02 and β by 0.04 with a minimum value of α as 0.75 and β as 0.67. It was proposed to maintain ultimate concrete strain at a constant value of 0.003 at par with ACI 318 .The error analysis proves the consistent conservativeness of the proposed parameters for both NSC and HPC [11].

Vatsal Patel and Niraj Shah (2013) High Performance concrete (HPC) has received increased attention in the development of infrastructure Viz., Buildings, Industrial Structures, Hydraulic Structures, Bridges and Highways etc. leading to utilization of large quantity of concrete. This paper presents a comprehensive coverage of High Performance concrete developments in civil engineering field. It highlights the High Performance concrete features and requirements over conventional concrete. Furthermore, recent trends with regard to High Performance Concrete development in this area

were explored. This paper also includes effect of Mineral and Chemical Admixtures used to improve performance of concrete. High Performance Concrete can be prepared to give optimized performance characteristics for a given loading and exposure conditions along with the requirements of cost, service life and durability. The applications of concrete will necessitate the use of High Performance Concrete incorporating new generation chemical admixtures (PCE based superplasticizers) and available mineral admixtures. The success of High Performance Concrete requires more attention on proper Mix Design, Production, Placing and Curing of Concrete. For each of these operations controlling parameters should be achieved by concrete producer for an environment that a structure has to face [12].

Hassan Baji and Hamid R. Ronagh (2013) The statistics of the equivalent rectangular stress block parameters was studied in this research. Performance of reinforced concrete members depends on many sectional and material variables that were statistically uncertain. Concrete properties and in particular equivalent rectangular stress block parameters were among those with high uncertainty. This paper describes fundamental statistical characteristics of the compressive stress distribution in the compressive zone of flexural members. Because most of the current design codes were using the equivalent rectangular stress block concept, the analysis in this study was based on this concept. Concrete stress block models in some of the current concrete design codes were reviewed and then, through probability-based model errors, these models were compared with the experimental data. The results show that due to variations in material and sectional properties, a significantly higher variability exists in the ultimate curvature of reinforced concrete beam sections in comparison to strength and that the ultimate curvature was sensitive to more random variables comparing to the strength [13].

Choudhary et.al (2014) The focus on High Performance concrete (HPC) has immensely increased due to utilization of large quantity of concrete, thereby leading to the development of infrastructure Viz., Buildings, Industrial Structures, Hydraulic Structures, Bridges and Highways etc. This paper includes the detailed study on the recent developments in High Performance Concrete, stressing more on the earthquake prone areas. It highlights the advantages and importance of High Performance concrete over conventional concrete and also includes effect of Mineral and Chemical Admixtures used to improve performance of concrete. The behaviour of SIFCON was also discussed briefly Slurry infiltrated fibrous concrete (SIFCON) was a composite material utilizing short steel fibres in a cement based matrix. SIFCON composites differs from conventional FRC in which the steel fibres were directly added to concrete mix in the ratio of 1-3% by volume, whereas, SIFCON uses matrix consisting of very fine particles leading to a bed of well compacted steel fibres in the range of 5-20% by volume . The fibers in SIFCON were subjected to frictional and mechanical interlock in addition to the bond with the matrix. The matrix plays the role not only of transferring of forces between fibers by shear but also acts as bearing to keep the fibers interlocked. The alternative for the HPC was also recommended. Many concrete products like Autoclaved Aerated Lightweight Concrete (AALC), Fiber Reinforced Concrete (FRC), and Lightweight Concrete, have been developed and experimentally verified [14].

Mahesh and Tatikonda (2015) Rice husk was an agro waste material which was produced in large quantity every year. It was normally used in the combustion process in lot of industries where heat was required. After this process of combustion the waste which was left over was called as Rice husk ash (RHA). RHA was a highly reactive pozzolanic material suitable for use in lime pozzolan mixes and for Portland cement replacement. RHA contains a high amount of silicon dioxide and its reactivity related to lime depends on a combination of two factors, namely the non-crystalline silica content and its specific surface. The mix design for concrete was prepared for M-60, M-80 and M-100 and the effect of

partial replacement of cement by 5%, 10% and 15% RHA was studied with respect to the reference mix. The variation of Poisson's ratio and modulus of elasticity of all the grades with 5%, 10% and 15% replacement of RHA was studied. It was found that for all the grades and mixes the value of poisson's ratio decreased for 5% replacement and for 10% and 15% replacement the poisson's ratio increased with respect to the reference mix. It was found that for all the grades and mixes the value of modulus of elasticity increased for 5% replacement and for 10% and 15% replacement the modulus of elasticity decreased with respect to the reference mix [15].

SUMMARY OF LITERATURE REVIEW

- High Performance Concrete can be prepared to give optimized performance characteristics for a given loading and exposure conditions along with the requirements of cost, service life and durability.
- Stress-strain model was developed for concrete subjected to uniaxial compressive loading and confined by transverse reinforcement.
- The proposals for the design of HPHSC beams, columns, and walls cover concrete grades in the range of 20 to 100MPa.
- The equivalent concrete stress block parameters of the eccentrically loaded specimen were obtained by adopting the modified stress-strain curve of its counterpart concentrically loaded specimen using a numerical analysis method.
- Stress-strain curve was affected by a lot of variables. So it was not possible to suggest a certain stress-strain curve for concrete.
- Although high performance was commonly used, its properties were not known as much as the properties of concrete in the design of reinforced concrete sections.
- The studies carried out show that such parameters can be chosen through simple relationships depending on the strength of non-confined concrete, on the amount and geometry of longitudinal and transverse reinforcement, and on the geometry of the section.
- The stress-block parameters can also derived from an analytic stress-strain model that was proposed to be particularly useful for hand analysis checks of various computational moment-curvature solutions.

CONCLUSIONS

- Rectangular stress block parameters used in ordinary concrete members cannot be used safely for high performance concrete members.
- The assumption that plane sections remain plane after deformation was valid.
- The ultimate concrete compressive strain value of 0.003 for design by the current code provision was acceptable.
- A Poisson's ratio of 0.2 as used in the current code provision was also acceptable.
- The stress block parameters formed was limited to use to a compressive strength of 120MPa.

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